

SOLAR PHYSICS

Background

Solar physics investigations have evolved to a state such that information in wavelengths and with techniques only possible from space platforms is crucial to the solution of most of the central problems in the discipline. In the recent past, observations from the OSO satellite series and Skylab have played major roles in the development of the field; and it is envisaged that the Solar Maximum Mission and Spacelab will likewise contribute substantially to future efforts.

Advantages of an STO

The Space Station will provide a unique opportunity for solar physics, for it is only from such a platform that studies of the evolution of solar phenomena over long periods can be attempted. Then it will be possible to mount programs of monitoring long-term variations in the solar output and state and employ the major solar facilities developed for Spacelab in the study of changes in the Sun over periods in excess of the Spacelab mission (a few weeks) duration. The Space Station offers unique capabilities for solar monitoring functions. It will be possible to include several experiments utilizing different techniques for solar constant, spectral irradiance, and cross-calibration purposes either on the station or a nearby tethered satellite (to avoid contamination problems) and to provide for absolute and relative calibration facilities on the Space Station itself. The correlation monitors will permit effective manned interface with the major solar instruments and with magnetospheric/atmospheric experiments

requiring specific solar conditions before initiation. Such monitors are discussed in this section.

Program of Investigations

The solar physics instruments for a space station can be divided into two general categories: solar situation monitors and major solar instruments. The former category includes: instruments to measure the solar output (e.g., solar constant and solar spectral irradiance); correlation monitors providing on-board scientists with full-disk, modest spatial resolution information for the purposes of interplanetary and terrestrial correlations, selection of solar regions for study by the major instruments, and pointing guides; and instruments providing correlative measurements (e.g., cross calibration with free-flying satellite experiments). The category of major instruments includes the more powerful state-of-the-art instruments designed with specific investigative tasks in mind. Such instrumentation may be applied to the solution of problems in solar physics whose relevance to specific solar-terrestrial problems is not entirely clear at the time. These instruments will provide the major observational inputs to the fundamental study of the Sun itself.

Solar experiments in the category of solar situation monitors include those which are of direct, fundamental relevance to the specification of the solar input to the terrestrial environment; foremost in this area are instruments to measure the solar constant and the solar spectral irradiance. It is now recognized that the determination of the total solar flux with high accuracy over a long time

period — several solar cycles — is required to assess its influence on the terrestrial climate. Further, it is generally accepted that such measurements must have high accuracy (better than 0.1 percent, or some five times better than that achieved before) if they are to serve as useful inputs to models of climatic variation. At that level of accuracy, the variation of solar flux due to the presence of sunspots is measurable and must be considered. These accuracies will require continued calibration which can be carried out by the on-board science staff. Since the interaction of the solar flux with the terrestrial atmosphere is a sensitive function of wavelength and is a maximum in the ultraviolet, it is also necessary to measure the solar spectral irradiance. The precise specification of the accuracies and spectral resolutions required must await detailed study, but generally it is anticipated that the principal wavelength region of interest is that of 2000-3500 Å, where stratospheric photochemistry is largely influenced; measurements of 1 to 2 percent accuracy are required in this spectral region. Shorter wavelengths, of importance higher in the atmosphere, require somewhat less accuracy, approximately 10 percent. Also, monitoring of the infrared solar flux to high accuracy may be important.

Another subcategory of measurements required includes instruments capable of monitoring the state of the solar disk. Included are modest spatial resolution instruments (2-5 arc sec) capable of specification of the solar state for (a) the terrestrial input, (b) selection of areas of interest for more detailed study (e.g., regions of emerging magnetic flux), and (c) determination of pointing requirements for the major solar instruments. These instruments will provide the real-time information upon which on-board scientists can base their tailored

observations of the coupled solar-terrestrial system. For example, X-ray or XUV images of the solar disk may provide knowledge of the presence of coronal holes in anticipation of relevant magnetospheric measurements days later. Observations of the solar disk with a tuneable visible light filter ($H\alpha$, H_e 10830 Å, etc.), with a magnetograph, or with an EUV monitor would permit selection of areas for intensive study or instrument pointing information. The X-ray and ultraviolet instruments, together with a white light coronagraph, would allow determination of the global characteristics of the chromosphere, transition region, and lower and outer corona for later correlation with solar and terrestrial results. Finally, this category of correlation monitors includes detectors of hard X-ray flux (≤ 500 keV), and possibly 10-cm wavelength flux, for the presence of impulsive solar events.

There remains in the category of solar monitors instruments capable of providing cross calibration with free-flying satellites; for example, calibration of results from such satellites as Solrad-High and GOES over extended periods through the simultaneous observation of solar events from the Space Station and the free-flyer.

In the following, we outline two general, yet directed, problems in solar physics which may be investigated from a space station in the period post-1985. The problems discussed are not necessarily intended to represent the most important problems of solar physics in that era; but, on the other hand, they represent questions of sufficient magnitude to be of substantial general interest in solar (and solar-terrestrial) physics at that time. It should be

noted that questions of central importance in other areas — the physics of solar flares, for example — will certainly be present in the era of the Space Station. However, because of the major observational effort to be directed toward understanding the flare problem during the Solar Maximum Mission and possibly its follow-on mission in the early 1980's, it is even more difficult to conjecture what specific problems will remain in flare physics than to predict the problems in the areas discussed in the following paragraphs.

Creation and Evolution of Solar Magnetism. The Sun is a magnetic variable star. In fact, the variability associated with solar magnetism is of dominant importance on Earth and throughout the solar system. The understanding of this cyclical phenomenon is a profound intellectual challenge that has eluded mankind since the discovery of the sunspot cycle. It is only recently, however, that the immense practical importance of this knowledge has begun to be appreciated.

The study of solar magnetism must encompass the emergence of new magnetic flux through the solar photosphere, the re-ordering of this flux into large-scale magnetic structures, and the extension of a portion of these magnetic fields into interplanetary space.

The majority of the solar magnetic field emerges in the form of sub arc-second flux ropes. The study of the formation and evolution of these small elements requires extended observations of the highest quality. Magnetographic (all Stokes' parameters) and velocity field measurements are required

at photospheric and chromospheric levels with a meter-class optical telescope with appropriate focal plane instrumentation. Observation of the extension of these fields to higher levels where the role of magnetic energy and thermal energy may be altered will require XUV and soft X-ray spectroheliographs with high spatial resolution.

There is good reason to believe that strong electric current systems develop in the course of the emergence and development of the magnetic fields. The restructuring of the fields associated with the dissipation of these currents and the reconnection of the fields into states of lower potential energy is accompanied by solar flares and the other dynamic processes associated with the life cycle of solar active regions. There is little hope of ever being able to trace these processes on the basis of Earth-based observations. Unbroken sequences of diffraction-limited operation are crucial, and concomitant observations at visible, XUV, and soft X-ray wavelengths are absolutely necessary.

As the magnetic field evolves over periods of days to weeks, we know that very large, ordered structures are formed. The present understanding of this process is inadequate. It is of utmost importance to achieve the best possible observational description of the coronal field topology as a function of time. This will require, in addition to the instruments mentioned previously, a white light coronagraph and a coronal emission line polarimeter. Technically more challenging is the task of measuring coronal field strengths.

The fundamental question of the nature of the solar cycle requires observational and theoretical study. Descriptive models based on flux diffusion under the influence of velocity fields, identified with chromospheric supergranulation cells, have been successful in reproducing some of the features of the solar cycle. However, improved observations of both the ordered and stochastic components of the velocity field with extended time sequences of the trajectory of individual magnetic flux elements in the photosphere, obtainable only from space-borne instruments, should shed considerable light on the subsurface convective forces which actually may drive this process. The instrumentation requirements are clear and technically feasible and the observational requirements definite. Furthermore, the theoretical tools necessary to understand and be tested by the observations are under development.

Mass Loss from the Sun. The great extent of the outer solar atmosphere, the corona, is a consequence of the high temperature of the gas. Furthermore, direct in situ observations have established that at the orbit of the Earth there is a continuous but strongly variable flow of plasma from the Sun — the solar wind. This mass loss is of fundamental astrophysical interest, and the details of the interaction of the magnetized plasma with the Earth and its magnetosphere are of major scientific and practical interest.

Progress to date toward an understanding of the origin, acceleration, and evolution of this mass flow has resulted from combined solar and interplanetary observations coupled with theoretical modeling of the processes

involved. An adequate physical description has yet to be formulated, although a close relationship between the properties of this mass flow and solar magnetism is established.

The desired fundamental understanding of the various aspects of this mass flow will require improved observations of the coronal mass and temperature distributions and their evolution in time. Crucial observations of the outwardly moving mass in the low corona can be obtained through Doppler shift observations with sensitive XUV spectrometers. High spatial resolution white light and Lyman alpha coronagraphs can provide information on temperature and velocity of outer coronal material. It is further necessary to specify the coronal magnetic field geometry as well as conditions at the base of the corona through the use of the optical and X-ray instruments mentioned earlier in the discussion of solar magnetism.

At some level the physical state of the extended solar corona changes from domination by thermal and magnetic energy densities to domination by the momentum of the flow itself. Also, the importance of observed wave and transient effects on the flow are poorly understood. Both radio and in situ particle and field measurements will help to address these aspects of the problem.

The assimilation of the many previously mentioned observations into a comprehensive theoretical description is a reasonable goal. A key element to the success of this study would be the detailed and comprehensive coverage

from a solar-terrestrial observatory module on a permanent space station.

Finally, there are two other important aspects of the future space station to consider. The first aspect concerns the use of man. Considerable expertise has been developed concerning the automation of sequences of observations, and by 1985 further experience in this field will have been acquired by a successful completion of the Solar Maximum Mission. Nevertheless, we foresee that some of the monitor-type experiments and, to an even larger degree, most of the research-type experiments will not be executed with the required performance to solve the problem in question without the intervention of a trained observer in the Space Station. The painstaking calibration and measurement accuracy needed for the solar-irradiance determination and the high pointing accuracy required for the small-scale magnetic-field observations are but two examples that indicate the necessity for manned intervention in well-planned observing sequences. With the sophisticated instrumentation we have proposed, other needs are highly likely to occur. These needs may include repair activities or the flexibility for observing complex phenomena — examples in which the Skylab experience demonstrated the desirability of man's presence.

The second additional aspect concerns the possible orbits of the future Space Station. A GEO permits nearly continuous observation of the Sun, whereas a LEO involves an approximately 30-min interruption of sunlight during every 1.5-hour cycle. Thus, for example, a GEO is highly desirable in order to track the detailed evolution of solar phenomena for time intervals exceeding an hour.

On the other hand, high-energy detectors may require special shielding to protect them from the relatively hostile space environment at the altitude of 6.6 Earth radii.